Electrostatic Fields Mediate Micro/Macro Coupling in Plasmas

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A crucial issue in modern physics is the ability to understand and model the coupling existing between large-scale and small-scale processes in nature and in the laboratory. In plasma physics, the issue can be best understood considering the simple picture of electric conductivity. We all learn in high school that electrical resistivity arises from collisions of electrons with the nuclei of the atoms forming the conducting materials. In very hot materials, the 4th state of matter, called plasma, is reached. Plasmas are nearly perfect superconductors and collisions are often nearly totally absent. Yet observations prove without doubt that plasmas display a behavior that is consistent with the presence of yet mysterious dissipation processes. Such processes are called "anomalous" for their unexplained nature.

Since the realization of the existence of such processes in natural and man-made plasmas, the scientific community has tried to arrive at an explanation of how such anomalous processes can be explained. Their origin is firmly established to come from the coupling of macroscopic processes with small-scale microinstabilities. But how are the microinstabilities affecting large-scale processes?

The dominant paradigm for the last few decades has been that of microscopic turbulence. The idea was that microinstabilities are seen by the plasma particles just like the collisions in the simple high school electrical conductor picture. Small-scale fluctuations in the electric field due to the microinstabilities scatter the electrons in the plasma and act just as collisions would, providing the needed dissipations. The explanation was compelling but the lack of theoretical or experimental confirmation for such a theory has been puzzling. In space and laboratory experiments, the lack of a clear link between fluctuations due to microinstabilities and anomalous effects has been proven in a number of works over the last 30 years.

We have now provided a possible alternative view. In a recent letter published by *Physical Review Letters* [2], we have discovered via simulations a new effect. We have conducted the largest ever kinetic plasma simulation, on the Q machine, and we have used our unique implicit kinetic plasma simulation code CELESTE to test via direct simulation the physics of micro-macro coupling.

The discovery is that the microinstabilities create directly a large-scale electrostatic field. The electrostatic field is macroscopic but is created by microscopic processes. The mechanism for such a remarkable effect is related to the action of the microinstabilities on the particle (specifically on the ion) trajectories. Unlike the effective collisions postulated by the old paradigm, the effect is now coherent and leads directly to a macroscopic alteration.

We report one instance of the creation of the large-scale electrostatic field in the Fig. 1. The small-scale instabilities are seen in the graininess of the data and are due to the so-called lower hybrid drift instability created by the density gradients present in the plasma [3].

Ongoing work is trying to determine whether our new paradigm can really apply in nature. We are conducting a data analysis campaign in collaboration with the Space Science and Applications Group (ISR-1) to identify the signature of our new model in satellite observations. We are also collaborating with the Plasma Physics Group (P-24) to conduct direct laboratory observations to detect the newly discovered electrostatic field.

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[1] G. Lapenta, *Space Sci. Rev.* **107**, 167 (2003).
[2] W. Daughton, et al., *Phys. Rev. Lett.* **93**, 105004 (2004).
[3] G. Lapenta, et al., *Phys. Plasmas* **10,** 1577 (2003).

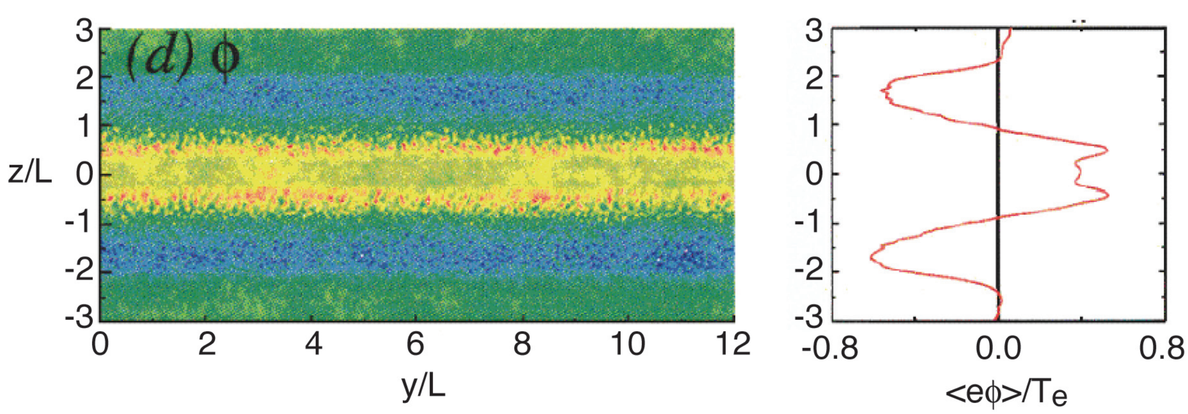

Fig. 1. ***Electrostatic potential formed by the large-scale consequences of microinstabilites. The averaged profile (red) is shown on the right. The crucial point is that the small-scale instabilities (observed in the graininess of the figure) lead directly to a large-scale electrostatic field.***